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SUBJECT: A Guide to Estimating the Effort Involved in Performing Life Support Analyses

PURPOSE

This paper discusses the effort involved in performing a trade study analysis in the life support and thermal community. It is specifically intended for people involved in the equipment selection process of the Advanced Life support Systems Integration Test Bed (ALSITB, also known as BIO-Plex). The BIO-Plex Project has requested comments and suggestions about their outline for the test article selection process (Smith, 1999). The following sections define the vocabulary used in this document and outline some general rules of analysis.

DEFINITION OF TERMS

Analysis: An analysis involves performing calculations to simulate or to predict performance of a process or system. These calculations are performed by hand or by using software. When software is used, the analyst creates a “model” to simulate the equipment or system.

Trade Study: A trade study consists of analyzing different equipment or subsystems by varying some characteristic parameters, while holding other parameters constant, and then comparing the results from different equipment or subsystem models.

System: A system such as BIO-Plex consists of several subsystems.

Subsystem: The subsystems, such as the Air Revitalization System (ARS) and the Water Recovery System (WRS), are comprised of equipment that perform all the functions required by the subsystem.

Equipment: Equipment are those articles that perform a function or functions within a subsystem, such as carbon dioxide removal equipment or the water recycling with a bioreactor.

<u>Equipment components</u>: Equipment components are the sub-assemblies of a piece of equipment. Examples of equipment components are the pumps, filters, and additional pieces that constitute the equipment.

GUIDELINES

The following are a few general rules to consider when planning analyses:

First, different equipment can be used to perform the same function. Yet, pieces of equipment with the same function do not necessarily interact with other equipment in the same manner. Different subsystem requirements may develop depending upon different equipment interactions. Therefore, equipment models are not necessarily interchangeable within a subsystem model without making extra modifications to the subsystem model (such as adding, deleting, or modifying other equipment models).

Second, equipment must be chosen and combined to perform all functions required by the subsystem. This choice is made with the aid of trade studies performed at the equipment level. Trade studies will predict a "best"[1] candidate for satisfying a particular function within the subsystem. However, since new requirements may develop depending upon how pieces of equipment interact, combining the "best" equipment, based on trade study results, may yield a subsystem that does not satisfy all requirements.

Thus, complete subsystems are compared with similar complete subsystems. This approach is valid, while comparing subsystems built from interchanged equipment models may not be valid.

The following example illustrates the above guidelines. First, suppose all equipment that could be used for the ARS has been modeled. Then, assume an ARS subsystem model has been created using the first equipment selection. This current hypothetical model has accounted for all trace contaminants created by the equipment within the subsystem. Next, suppose the carbon dioxide reduction equipment model is replaced in the subsystem model with a different carbon dioxide reduction equipment model. A problem may arise because the new equipment model produces a trace contaminate gas that is not a part of the original subsystem model. The current subsystem model is not valid unless a new trace contaminate equipment, which will remove the new trace contaminate gas, is included into the subsystem model, and the subsystem model is changed to account for the new trace contaminate gas. For this reason, subsystems should be chosen and compared rather than equipment.

ANALYSIS EFFORT

A specific goal must be defined before analysis effort can be estimated. This document provides background information to allow an analysis customer to define analysis products as a function of resources required. The customer of the analysis needs to select the scope, the level of detail, the

[1] The meaning of "best" pertains to either the best candidate or the top members. Currently the outline suggests choosing the top three candidates (Smith,1999).

desired fidelity, and the availability of information; this will determine the requisite effort to complete the analysis.

Scope

The scope of an analysis can be as selective as a single equipment component or as broad as an entire system. For an analysis of an equipment component, configurations using different parts are compared. For a system level analysis, configurations with variations at any subordinate level are compared. Such subordinate levels include, in descending order, subsystems, equipment, and equipment components. A four-bed molecular sieve is an example of equipment while an ARS is an example of a subsystem. Thus, an analysis at the system level encompasses the entire system, which can include all subsystems and all equipment in those subsystems and all interactions between the equipment. Generally, more effort will be necessary as the scope of the analysis becomes broader.

Level of Detail

Analysis complexity and the corresponding required effort can vary depending on the level of detail requested. Crew and Thermal Systems Division (CTSD) uses three classifications of detail. The Level 1 model has the least. A model with the first level of detail can also be described as a “top-level” model. Level 1 models are often system level and independent of time. They are generally built using Excel or similar software. The Level 2 model is more detailed and generally includes the system dynamics. This level of detail is sufficient to describe the system as a whole, but it lacks the component detail of the third level. A Level 3 analysis is an in-depth evaluation of a piece of equipment. The third level of detail is generally used to compare equipment or equipment components. The Level 3 analyses is usually time dependent or transient but they usually consider additional details such as chemistry and engineering equations. System level models are usually not constructed at this level because the resources required are prohibitive. Most system and subsystem trade studies are conducted at the first or second level of detail. A drawback with a Level 1 analysis is that it may not model equipment interactions within the system in sufficient detail. Generally, a more detailed analysis will take more time and greater effort.

Accuracy of Results

As modeling results depend on input values, the accuracy of the results is a strong function of the quantity and quality, or accuracy, of the input values. To maintain the same level of accuracy as the scope of a model increases, the required quantity of input values generally increases. Thus, to maintain highly accurate results, a system-level model requires considerably more accurate information than a model of a piece of equipment. When the prescribed input values are not available, either an estimate or an assumption is used to bridge the deficiency. Since estimates or assumptions are often less accurate than the information they are replacing, the accuracy of the results decreases. While a high level of accurate results may be required for some predictions, such as Level 3 analysis of individual pieces of equipment, less accurate results may be acceptable for a Level 1 system-level trade study.

Flight-ready equipment generally have more accurate information than experimental equipment. Doing highly detailed analyses on experimental equipment may not be productive due to the possible lack of accurate results. Since the accuracy of the available information is diminished at lower development levels, detailed analyses of experimental equipment may give approximately the same results as a less detailed analysis. The general trend is for analyses to require more resources to yield results with greater accuracy.

Availability of Information

At the start of the analysis, the amount of information available also plays an important role in the amount of time an analysis will require. If prior analyses have already been performed on the subject, if information has already been gathered, or if the analyst has experience with the subject, the analysis can be performed with less effort. Since most analyses are requested for new equipment or unknown equipment interactions, information typically must be gathered before models can be developed. A lack of readily available information increases the effort needed to complete the analysis.

SUMMARY

The exact effort required to complete an analysis is unpredictable. However, a low-level analysis of a system in which most subsystems are already understood and well-defined will generally require less time than a highly detailed analysis of a single equipment for which no information is readily available. The software selected is highly dependent on the desired analysis product. Sometimes the available software is not capable of performing an analysis, so more capable software must be used or acquired. If prior modeling has been completed with the same software, the required effort is reduced. However, additional time may be required when modifying prior models if the analyst is unfamiliar with them. The steps involved in preparing for an analysis are in the following section summarized.

ANALYSIS CHECKLIST

Before starting an analysis, the scope, level of detail, fidelity, and the availability of information must be determined. The following outline lists the order in which topics should be considered and what general options are available for each of the topics.

I. Scope of Analysis
   A. System
   B. Subsystems
   C. Equipment

II. Level of Detail
   A. Level 1
   B. Level 2
   C. Level 3

III. Accuracy of Results
   A. High
   B. Medium
   C. Low

IV. Information Availability (at start of analysis)[2]
   A. Available
   B. Must be Gathered

CONCLUSIONS

Trade study analyses take a varying amount of time depending on many factors:

- As noted in the appendix below, it will take about two to three months for any equipment-level trade study and about six months to a year for any subsystem trade study of moderate to high detail.
- Scope is the most significant attribute that determines the effort of an analysis project.
- Low detail models or models with low fidelity requirements may take less time (one to three months with a scope of equipment level).
- These times may be increased due to inexperience with the particular equipment or due to the lack of information available at the start of the analysis.
- The analysis will require more time if a high fidelity model is desired. The level of confidence in the results depends on the quality and quantity of information available.
- Software is a tool the analyst uses and is typically chosen by the user based on the needs of the customer. The choice of software has little effect on the amount of time an analysis will take when the software is chosen appropriately.
- Equipment models are not "plug-and-play" within a subsystem model and additional time may be required to determine and to account for interaction between the pieces of equipment.

[2] Depends currently on Step III.B in outline (Smith, 1999).

- A system level model of high detail that allows equipment to be interchanged does not exist currently. The resources to develop such a model would be significant.[3]

REFERENCE

Knox, James C. [NASA /MSFC /ED62], October 28-29, 1998. Comments at a Systems Modeling and Analysis Workshop in Houston, TX.

Smith, Frederick D. [NASA /JSC /EC3], January 27, 1999. Draft of “LSS Test Article Selection Process for the ALS Systems Integration Test Bed (BIO-Plex)” and collection of communications.

[3] Analysts at Marshall Space Flight Center (MSFC) developed an overall model for the International Space Station life support system. They noted that the model, after significant development, was often inefficient to run due to its high level of detail (Knox, 1998).

APPENDIX: LIST OF AVAILABLE SOFTWARE

The following are examples of software that have been used in past analyses. Some of the following software, such as STELLA, CASE/A, and G189A, are no longer supported. Because of the lack of support, these programs are rarely selected for new modeling tasks. After a brief description of each software, examples of prior analyses performed by CTSD are provided. These analyses were conducted by the Thermal, Fluid Flow, and Systems Engineering Section at Lockheed Martin Space Operations Company unless otherwise noted.

Excel

Excel is a spreadsheet program. It is readily transferable between analysts because of its widespread use. One problem is that Excel can not solve many higher-level mathematical functions, such as differential equations without adding user defined routines. Further, since the information and formulae are embedded in cells, an understanding of the spreadsheet can not be reached without comprehensive documentation or an in-depth examination of the mechanics of the spreadsheet. This program best handles top-level (Level 1) analyses that involve little detail.

1) An equipment level model with low detail required 2 - 3 months.
2) A subsystem level with low to semi-moderate detail required about 3 - 4 months.
3) An overall system level model including bioregenerative systems at low detail required 6 - 9 months.
4) An overall system level with all known equipment choices and very low detail required about 12 - 18 months.

SimuLink/ MATLAB

SimuLink is the graphical user interface (GUI) for MATLAB. The user can build equations to model static or dynamic processes. The major downfall of this program is that models are not easy to modify. This is because the analyst must not only change the connectivity of the individual components but may also need to modify the time-based components within the model. This program can go into a moderate amount of detail (Level 2) if sufficient information is available. It could generate highly detailed (Level 3) models if all applicable information were available. However, this program would probably not be the best candidate for Level 3 analyses because of the amount of time necessary to build the entire model.

1) An overall dynamic system model, which included moderate detail in some subsystems and low detail in the others, had an overall moderate detail level. It required approximately 6 months to create and about 5 weeks to modify. This work was performed at Ames Research Center.

Aspen Plus/ Custom Modeler

Aspen Plus/ Custom Modeler are detailed process solvers created by Aspen Technologies. They are two separate programs that allow the user to use pre-built (Plus) or custom-built (Custom Modeler) blocks. These programs are built with many of the robust chemical and engineering equations necessary to solve Level 3 analyses.

1) A highly detailed equipment level model required 3 - 4 months to develop with Aspen Plus.

STELLA

STELLA is an in-house-developed program that functions as an overall life support model architecture. This program is not used as much today as it was in prior years. STELLA solves mass balances dynamically and does not allow modeling of individual equipment. Because of this issue, STELLA is not used currently.

1) A subsystem model was developed in STELLA with low detail and it took approximately 6 months to complete.

SINDA/ FLUINT

SINDA is a commercial program that solves for the flow of heat within the user-defined nodular model. FLUINT is a separate companion program that integrates fluid flow within the model. The two programs can work together to help describe a system from both thermal and fluid flow standpoints. Since the programs are written in a programming language, additional programming can be added to increase the detail of the model. The level of detail that this program can model depends upon the quality of the input information. One particular downside is that there are no checks involved, and it will not alert the user to inconsistencies within the model.

1) An equipment level analysis of moderate detail required 3 months.
2) The thermal subsystem of BIO-Plex with moderate detail has required 4 months so far.
3) To update a space shuttle model to include pressure loss and payload heat performance required about 6 months.

FLUENT

FLUENT is a Computational Fluid Dynamics (CFD) solver. This program will solve the governing mass, momentum, and energy equations pertaining to fluids in a three-dimensional (3D) space. This program can compute the movement of fluid within an enclosed space such as a cabin. Again, the level of detail that this program can model is limited by the quality of the input information level.

1) The TRANSHAB module was developed to moderate detail and required 2 - 3 months.
2) An equipment analysis that involved high detail required 2 - 3 months to develop.

G189A

G189A was developed by the space industry specifically to simulate life support systems. It was written in FORTRAN and has been useful in past modeling attempts. This program can provide all levels of detail. CASE/A is a similar program. The problem arises in that G189A and CASE/A are no longer offered nor supported.

1) Four moderately detailed analyses that involved modifying an existing model required 7-8 months.
2) A moderately detailed model of a BIO-Plex subsystem required 2 months.

TSS

Thermal Synthesizer System (TSS) is used to determine geometric relations for radiant heat transfer. This program calculates the view factor based on the given geometry. Coupled with SINDA, the temperatures of the various surfaces can be computed. This program can also simulate solar and planetary radiation effects on an object.

1) A moderately detailed equipment level analysis required 3 months.

MathCad

This commercial mathematical solver is excellent at solving algebraic equations, differential equations, and general mathematical relationships. It solves matrix equations and has graphing capabilities as well. There are other programs similar to this program, such as MAPLE and Mathematica. A problem with modeling with these types of programs is their awkward spreadsheet functionality. One benefit is that the output from using MathCad is self-documenting.

Programming Languages

Some examples of programming languages include FORTRAN, C++, BASIC, and OpenGL. The benefit of building personal programs is that the analyst can create everything that is needed. However, the model may require a lot of programming relative to the results generated. Another problem arises because different analysts usually find it hard to use a custom program because every programmer essentially uses a unique programming style.

1) A moderately detailed equipment level program averaged about 3 months to develop in FORTRAN.
2) A moderately detailed subsystem model averaged 8 to 9 months to complete.
3) A moderately detailed model combining two subsystems (ARS and WRS) required about a year to complete.

Specialty Programs

A number of specialty programs exist that model very specialized equipment and processes. These programs were not listed because of their restricted applicability. They generally model equipment or processes in great detail, but they require accurate data.

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